STANDARDIZATION OF WIND PRESSURE AND TEMPERATURE VARIATIONS AS REGARDS THE DESIGN OF OVERHEAD LINES WITH PARTICULAR REFERENCE TO CONDITIONS IN WEST BENGAL*

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ABSTRACT. In the present paper a modified formula for calculating the tension of overhead transmission lines has been developed after critically examining the climatic conditions prevailing in the state of West Bengal. It is found that we are increasing unnecessarily the cost of construction of such overhead lines by using the existing formula which is based on climatic conditions not prevailing in this state.

INTRODUCTION

Overhead line design is generally governed by official regulations which lay down factors of safety, loading conditions, minimum ground clearances, and provisions relating to road crossings, telephone interference, etc. The object of the present paper is to discuss the adequacy or otherwise of the existing regulations for meeting the climatic conditions prevailing in West Bengal.

EXISTING REGULATIONS

The design conditions specified for the state of West Bengal are briefly as follows :

(1) Ice loading is to be ignored.

(2) The minimum and maximum temperatures specified are 50°F and 130°F respectively.

(3) The wind is assumed to blow horizontally on the line conductors and to exert a pressure equivalent to 20 lb. sq. ft. calculated on ⅔rd of the projected area of the conductors.

(4) Factors of safety.

(*i*) 2, for conductors (under conditions of maximum loading and minimum temperature).

(*ii*) 2.5, for metal supports (wind assumed to exert a pressure equivalent to 20 lb./sq. ft. on 1½ times the area of one face of the support.)

(*iii*) 3, for guard wires or bearer wires.

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(5) The minimum height of conductors is to be not less than 20 ft. from the ground at any point of the span at a temperature of 130°F.

The loading conditions in Bengal are not only less severe than in the U.K. but there is less difference between the loaded and unloaded conditions. The same minimum figures for safety factors as El.C.53 in the U.K. are, however, specified : this would appear to be unreasonable.

PROPOSED ALTERATION OF REGULATIONS

The loading conditions adopted by the different Indian Provincial Governments have been criticised as irrational, and further consideration has been recommended with a view to reduction in line costs (Coventry, 1949).

In Britain also, as the result of extensive experience of high-voltage overhead lines, suggested modifications of the present code of Overhead Line Regulations El.C.53 (1947 Revised) have been published (Grimmitt, 1949) to elicit criticism before the preparation of a final draft.

The object of the proposed amended regulations is to reduce the capital cost of overhead lines, to simplify construction, to reduce ground clearance and to improve appearance without affecting public safety.

Many of these suggestions will, no doubt, be suitable to Indian conditions, and if implemented will materially reduce the cost of line construction. As examples the following may be cited :

(a) *Minimum Conductor Ground Clearance.*

This is 17 ft. for 11 kV lines, and 20 ft. upto 66 kV lines, except at road crossings where the clearance is 19 ft. for 11 kV and 20 ft. for the higher-voltage lines.

(b) *Earthing and Bonding.*

The new regulations permit non-earthed metal work on wood pole supports.

(c) *Road Crossings.*

It will not be necessary to provide duplicate insulators, earth bars or arching horns at road crossings. The construction will be similar to that for normal spans, subject to the use of insulators of the next higher rating to that recommended in Table 2 of B.S. 137, 1941 for the appropriate line voltage.

(d) *Factors of Safety.*

There is a suggestion for dropping of the term " Factor of Safety " in the case of overhead lines. An empirical formula has been proposed for tensioning line conductors. Such tension is not to exceed 75% of the breaking load at 22°F instead of 50% as hitherto.

It is noteworthy that the Central Electricity Commission in India has directed its attention to the question of standardization of wind pressure and temperature variations to be adopted for simplification of overhead line design and construction.

SPECIAL FEATURE PERTAINING TO WEST BENGAL

In planning a regional scheme for electrification, it is necessary to consider the special local climatic and geographical conditions prevailing.

(1) *Temperature.*

To estimate the normal variations of temperatures to be expected in the area, Table I has been compiled from records of the Meteorological Dept., Alipore (Calcutta) (Lat. 22°32′ N; Long. 88°20′ E; height 20 ft.)

TABLE I

Maximum and minimum shade temperatures, °F

Months	1941		1942		1943		1944		1945		1946		1947	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jan. ...	84	49	84	51	88	52	89	50	86	47	87	47	83	50
Feb. ...	93	54	94	50	88	49	90	54	92	49	93	55	90	52
Mar. ...	106	63	101	64	101	60	97	63	100	57	102	62	100	63
Apr. ...	107	73	103	69	101	67	101	66	101	68	96	68	108	74
May ...	102	72	108	74	100	73	105	72	100	72	101	69	103	73
June ...	100	74	106	76	97	74	109	75	104	76	98	74	99	75
July ...	95	75	95	77	95	76	95	76	94	78	93	76	95	78
Aug. ...	95	75	93	75	93	76	97	75	96	76	...	...	95	75
Sept. ..	96	77	93	76	95	77	95	75	94	76	95	75	96	76
Oct. ...	95	67	94	71	95	68	94	67	94	70	93	69	95	66
Nov. ...	90	57	89	61	92	59	92	55	89	57	88	59	92	59
Dec. ...	86	53	86	50	85	55	86	51	84	47	86	54	86	51

Approximate additions to above for sun temperatures in °F are as follows:

Jan. 55; Feb. 64; March, 63; April, 62; May, 66; June, 71; July, 71; Aug. 67; Sept. 66; Oct. 67; Nov. 62; Dec. 65.

The figures in Table I indicate that the normal range of shade temperature variation is 47° – 109°F, no temperature higher than 109° having been recorded during the last 10 years. The corresponding sun temperatures are 47° + 55° = 102°F in January and 109° + 71° = 180°F in June. Thermal ratings of transformers and feeder equipments have to be reduced considerably in view of these high ambient temperatures.

(2) *Wind Velocities.*

Table II gives the maximum wind velocities recorded at the Alipore Observatory for the years 1939–47.

TABLE II

Maximum wind velocities in m.p.h.

—	1939	1940	1941	1942	1943	1944	1945	1946	1947
Jan. ...	28	21	45	20	22	27	18	24	30
Feb. ..	38	43	37	44	39	37	26	32	27
Mar. ..	33	53	34	36	46	51	29	38	35
Apr. ...	40	35	52	46	46	42	39	62	38
May ...	74	60	48	50	44	46	36	80	48
June ...	64	67	46	50	39	50	...	52	49
July ...	35	69	43	50	40	34	...	44	40
Aug. ...	57	33	47	34	30	27	...	34	48
Sept. ...	39	41	37	30	38	25	...	36	32
Oct. ...	29	31	33	67	39	30	...	50	40
Nov. ...	28	20	22	34	20	20	28	22	22
Dec. ...	20	23	20	22	20	16	28	26	26

...... No record.

The table indicates that the maximum wind velocities were recorded in summer months for each of the nine years of record examined. Meteorological records also show that over the same period only on three days did the maximum velocity exceed 70 m.p.h. and that only for a few minutes. The normal wind velocity seldom exceeded 30 m.p.h.

The effective wind pressure on a plane surface may be obtained from $p=0.0032\ V^2$, where p is the pressure in lb./sq. ft. exerted by a wind of velocity V m.p.h. In calculating pressure, only the projected area of the surface need be taken into account. For circular conductors the streamlining of the air flow permits two-third of the projected area to be used. For the maximum recorded velocity of 80 m.p.h., wind pressure is 20.5 lb./sq. ft. For a velocity of 30 m.p.h., the corresponding pressure is only 2.88 lb./sq. ft. It is to be noted that the worst wind loading condition does not occur at the time of minimum temperature, when the stress in the conductor is high, but is to be expected in the summer, when sudden squalls of short duration may occur. During the low-temperature period the wind loading is relatively light.

As tower costs are affected by sag, it is a matter for careful consideration whether conductors should be strung at maximum temperature to a definite tension limit or to a higher sag. This is discussed more fully later.

Further, the British proposal to drop "factor of safety" in favour of an empirical formula for tensioning line conductors presents the question whether this method could be satisfactorily applied in West Bengal. Here maximum working stress in the conductor does not occur at the minimum temperature where no wind loading is likely to be encountered, unlike the usual limiting consideration of the existing regulation, *i.e.*, maximum working tension at minimum temperature with maximum loading. The maximum sag of conductors also would occur at maximum temperature with maximum loading and this condition determines the height of the supporting structure.

MODIFIED FORMULA FOR CALCULATION OF SAG

The line must be erected so that at the conditions then prevailing, usually a lower temperature and no wind, the above conditions are complied with.

Let w — the weight in lb. per foot of conductor.

W — the resultant pressure in lb./foot of line when subjected to wind.

Z_q — ($\frac{1}{2}$) length of the line in ft. under worst condition at maximum temperature and maximum wind pressure.

T_q — the line tension in lb. being half the breaking load.

t° — the erection temperature in defect of 130°F.

Z_t — the line length in feet during erection, *i.e.*,$(130^\circ - t^\circ)$, assuming still air.

T_t — the tension at erection.

E — the modulus of elasticity in lbs./sq. inch

a — Cross-sectional area of the line in sq. inch.

λ — $E \times a$ (modulus of the wire of area a).

α — co-efficient of linear expansion of the material of the conductor.

The line will contract due to thermal effect for a temperature fall of t°F by an amount $= Z_q \alpha t$.

The line will also contract elastically when wind load is removed by an amount β.

Calculation of β.

$$\text{We know, } \frac{\text{change of stress}}{\text{change of strain}} = E.$$

$$\text{change of tension} = T_q - T_t$$

$$\text{change of stress} = \frac{T_q - T_t}{a}$$

$$\text{change in strain} = \frac{\beta}{Z_q}$$

$$\therefore \quad \frac{T_q - T_t}{a} \cdot \frac{Z_q}{\beta} = E$$

or
$$\beta = Z_q \frac{T_q - T_t}{\lambda}$$

Hence the total contraction $(Z_q - Z_t)$

$$= Z_q \alpha t + Z_q \frac{T_q - T_t}{\lambda}$$

Hence the line length at erection is given by

$$Z_t = Z_q \left(1 - \alpha t - \frac{T_q - T_t}{\lambda}\right)$$

$$= l\left(1 + \frac{l^2 W^2}{6T_q^2}\right)\left\{1 - \alpha t - \frac{T_q - T_t}{\lambda}\right\}$$

$$\left(1 + \frac{w^2 l^2}{6T_t^2}\right)$$

Neglecting product of small quantities the above equation may be reduced to the form

$$T_t^3 + T_t^2 \left\{\frac{W^2 l^2 \lambda}{6T_q^2} - \lambda \alpha t - T_q\right\} = \frac{w^2 l^2 \lambda}{6} \quad \ldots \quad (1)$$

which is of the form

$$T_t^3 + T_t^2 A - B = 0$$

This is a cubic equation in T_t and may be solved by a graph or by Newton's approximation or by slide rule.

It may be remarked here that the existing formula is

$$T_t^3 + T_t^2 \left\{\frac{W^2 l^2 \lambda}{6T_q^2} + \lambda \alpha t - T_q\right\} = \frac{w^2 l^2 \lambda}{6} \quad \ldots \quad (2)$$

which is being wrongly used on the assumption that worst loading condition occurs at the time of minimum temperature during winter months, while the statistical data mentioned earlier clearly indicate otherwise.

The positive sign before $\lambda \alpha t$ indicates that the erection temperature is higher than the temperature when worst loading condition will occur. But in equation (1), $\lambda \alpha t$ is negative because the erection temperature is below the temperature of worst loading condition.

For a comparative study an example is given below.

OVERHEAD LINE DESIGN AND CALCULATION OF TENSION

Basis

Span – 400′
Size of conductor – 3/.147 or .05 sq. inch copper equivalent.
Temperature – min – 50°F
max – 130°F

Wind pressure = 20 lbs./ sq. foot
Wt/ft. run of conductor = .200 lb.

Windage $= \frac{.317}{12} \times 20 = .528$ lb.

Resultant wt/ft. of conductor including windage

$$= \sqrt{.528^2 + .2^2} = \sqrt{.04 + .279} = \sqrt{.319} = .565 \text{ lb.}$$

Breaking load = 2920 lb.

Safe working load $= \frac{2920}{2} = 1460$ lb. (assuming factor of safety 2)

$$E = 18 \times 10^6 \text{ lbs./sq. in.}$$
$$\alpha = 9.22 \times 10^{-6}\ ^\circ\text{F}$$
$$\lambda = Ea$$
$$\lambda\alpha t = 18 \times 10^6 \times 9.22 \times 10^{-6} \times .05 \times t$$

$$\frac{W^2 l^2 \lambda}{6 T_q^{\,2}} = \frac{.565^2 \times 200^2 \times 18 \times 10^6 \times .05}{6 \times 1460^2} \quad 900$$

$$\frac{w^2 l^2 \lambda}{6} = \frac{.2^2 \times 200^2 \times 18 \times 10^6 \times .05}{6} = 240 \times 10^6$$

Table III

Tension at different erection temperatures (without wind load)

Temperature °F	Existing formula		Modified formula	
	Equation	Solution. Tension in lbs.	Equation	Solution. Tension in lbs.
130	$T^3 + 104\, T^2 = 240 \times 10^6$	588	$T^3 - 560\, T^2 = 240 \times 10^6$	874
120	$T^3 + 21\, T^2 = 240 \times 10^6$	615	$T^3 - 643\, T^2 = 240 \times 10^6$	924
110	$T^3 - 62\, T^2 = 240 \times 10^6$	643	$T^3 - 726\, T^2 = 240 \times 10^6$	977
100	$T^3 - 145\, T^2 = 240 \times 10^6$	674	$T^3 - 809\, T^2 = 240 \times 10^6$	1034
90	$T^3 - 228\, T^2 = 240 \times 10^6$	708	$T^3 - 892\, T^2 = 240 \times 10^6$	1093
80	$T^3 - 311\, T^2 = 240 \times 10^6$	745	$T^3 - 975\, T^2 = 240 \times 10^6$	1155
70	$T^3 - 394\, T^2 = 240 \times 10^6$	785	$T^3 - 1058\, T^2 = 240 \times 10^6$	1219
60	$T^3 - 477\, T^2 = 240 \times 10^6$	828	$T^3 - 1141\, T^2 = 240 \times 10^6$	1286
50	$T^3 - 560\, T^2 = 240 \times 10^6$	874	$T^3 - 1224\, T^2 = 240 \times 10^6$	1355

TABLE IV.

Tension for different span lengths at 130°F (without wind load).

Span in ft.	λat		$\frac{w^2l^2AE}{6T_0^2}$		$\frac{w^2l^2AE}{6}$		Equation		Tension (lbs)	
	for existing formula.	for modified formula	for existing formula.	for modified formula.	for existing formula	for modified formula	by existing method	by modified method.	by existing method	by modified method.
375	664	0	789	789	211×10^6	211×10^6	$T^3-7T^2=211\times10^6$	$T^3-671T^2=211\times10^6$	598	920
400	664	0	900	900	240×10^6	240×10^6	$T^3+104T^2=240\times10^6$	$T^3-560T^2=240\times10^6$	588	874
500	664	0	1405	1405	375×10^6	375×10^6	$T^3+609T^2=375\times10^6$	$T^3-55T^2=375\times10^6$	565	740
550	664	0	1700	1700	453×10^6	453×10^6	$T^3+904T^2=453\times10^6$	$T^3+240T^2=453\times10^6$	557	696
600	664	0	2025	2025	540×10^6	540×10^6	$T^3+1229T^2=540\times10^6$	$T^3+565T^2=540\times10^6$	550	663

Erection temperature = 130°F *i.e.* rise of temp. t = 80°F (for existing method). Defect of temp. t = 0°F (for modified method).

It is assumed that at the time of erection there will be no wind load.

CONCLUSIONS

Tables III and IV show the increased tension of the order allowed by the modified formula. It will be clearly seen that the lines may be stressed to considerably reduced sag to obtain much larger spans with the same height of pole and same clearance.

The condition stipulated by the modified formula exists on the warmer and central side of West Bengal where at the temperature of 50°F (assumed minimum temperature), a wind loading which produces a horizontal pressure of 20 lbs. per sq. ft. upon the "projected area" is never obtained. It is thus evident that by using equation (2), which is based on the prevailing British climatic conditions, one increases unnecessarily the cost of overhead line construction.

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REFERENCES

Coventry, 1949, *Proc. I.E.E.*, **96** (II), 521.
Grimmitt, 1949, *Proc. I.E.E.*, **96** (II), 673.